6778001

PHILCO CORPORATION

A SUBSIDIARY OF Ford Motor Company

SCIENTIFIC LABORATORY • Blue Bell, Pennsylvania

Mitchell 6-9100

8p.

Pa. Scientific Lab.

26 September 1963

N64 11109

CODE-1

(NASA CR-52859)

OTS: $1.10ph, $0.80mf

TO: NASA Headquarters
Washington, D. C., 20546
Attention: Code RET

SUBJECT: Theoretical and Experimental Investigation on Modulation Inducing Retrodirective Optical Systems, (NASA Contract NASw-721) (~~10-804) (10-1227), (Philco B003)~~, Monthly Contract Progress Report No. 4, ~~for the period of~~ 21 August 1963 ~~to~~ 21 September 1963.

[2]

MEETINGS BETWEEN CONTRACTOR PERSONNEL AND TECHNICAL SUPERVISOR

A meeting was held on 26 August 1963 at the Philco Scientific Laboratory to duscuss progress in the MIROS work. Dr. J. Walker and Mr. R. Chase of NASA Headquarters and Drs. Lasser, Lucovsky, Cholet, and Harned and Messrs. Leder, Emmons, and Mace of the Philco Scientific Laboratory took part in the discussion, which dealt with the operation of the optical pumping of cesium and an exhibition of the experimental set-up.

In the demonstration it was shown that a chopped cross beam is capable of introducing a modulation to the main transmitted light beam. It was pointed out that two other low frequency beams may be used for cross modulation; however, no experiment had yet been undertaken to show the effect. Because of the difficulties encountered in this work with inefficient cesium sources, the advantage of using an injection laser as pumping source was discussed. The band edge shifting work was reviewed by Dr. Lucovsky, and possible experimental variations of the principle were mentioned. It was agreed that auxiliary units are permissible at the MIROS element to assist in performing the desired modulation transfer, provided the passive nature of the assembly is maintained; the example discussed was the use of solar cells for providing the necessary fields for the band edge shift. It was also agreed that one of the two beams could be at microwave frequencies. Further discussion at the meeting pertained to coherence effects and, in particular, to the optimum size of the collecting surface for coherent radiation propagating through the atmosphere.

B. W. Harned and M. E. Lasser

26 Sep. 1963 8p refs

OTS PRICE

XEROX $ 1.10 ph

MICROFILM $ 0.80 mf

SUMMARY OF WORK ACCOMPLISHED DURING THE REPORT PERIOD 11109

The effort during the reporting period was devoted entirely to further exploration of the optical pumping, although it had been anticipated at the start of the period that other systems would be analyzed in some quantitative detail. The results of the work appear extremely encouraging for the MIROS program and lend support to earlier claims of various system possibilities. Previous reports that microwave and low radio frequency signals can disturb optical alignment were confirmed ~~during~~ this period in experimental tests which indicated other means for cross modulation. The suggested use of magnetic fields to alter population was attempted, and it was found that current from a solar cell introduced to a pair of electromagnets was sufficient to produce the desired result. Variations in optical equipment and adjustments provided additional useful information.

AUTHOR

TECHNICAL DISCUSSION

A. Power Considerations

Pursuing the power level considerations during the reported meeting with Dr. Walker and Mr. Chase, some simple calculations were made to determine levels of expected return signals for various transmitted laser power levels. Table I was derived for the reduction in transmitted power per cm^2 at various distances, r, for various beam divergence angles, θ, computed according to $(r\theta)^{-2}$. A round trip for any transmitted and reflected beam would be expressed by the square of one of these terms, modified by the collecting surface area at the target and the collecting surface area at the receiver under the assumption of negligible scattering and distortion of phase characteristics. Thus, ideally, a 10 watt/cm^2 laser beam of 10 sec divergence angle reflected from a 1 sq. meter stationary satellite and collected by a 100 cm^2 mirror at the receiver would provide a quite usable signal of 10^{-10} watts. The power incident on the MIROS element is 3.3×10^{-8} watts/cm^2 or about 1.5×10^{11} photons/cm^2 sec at the cesium wavelength of interest. These values indicate the need for very sensitive MIROS elements which are capable of responding at microwatt levels.

B. Optical Pumping Theory

Details of optical pumping have been omitted in previous reports, but experiments conducted during this period and described later, suggest that the specific atomic levels involved be identified.

Optical pumping of an alkali metal vapor results in a preferred population of atoms in one or more of the magnetic sublevels of the ground

TABLE I

POWER IN WATTS PER SQUARE CENTIMETER RECEIVED AT DISTANCE (r) FROM 1-WATT POINT SOURCE WHOSE RADIATION DIVERGES IN ANGLE (θ)

θ (sec) \ r	100 mi.	1000 mi.	10,000 mi.	22,289 mi.
1	1.64×10^{-2}	1.64×10^{-4}	1.64×10^{-6}	3.3×10^{-7}
5	6.5×10^{-4}	6.5×10^{-6}	6.5×10^{-8}	1.3×10^{-8}
10	1.64×10^{-4}	1.64×10^{-6}	1.64×10^{-8}	3.3×10^{-9}
15	7.2×10^{-5}	7.2×10^{-7}	7.2×10^{-9}	1.3×10^{-9}
20	4.1×10^{-5}	4.1×10^{-7}	4.1×10^{-9}	8.2×10^{-10}
25	2.6×10^{-5}	2.6×10^{-7}	2.6×10^{-9}	5.2×10^{-10}
30	1.8×10^{-5}	1.8×10^{-7}	1.8×10^{-9}	3.7×10^{-10}
60	4.5×10^{-6}	4.5×10^{-8}	4.5×10^{-10}	9.2×10^{-10}

state. All alkali metals (one-electron atoms) possess a $^2S_{1/2}$ (doublet) ground state, where the hyperfine splitting of the two levels of this doublet depends on magnetic interaction of the atomic electrons with the nucleus. Application of an exterior magnetic field causes further (Zeeman) splitting into the allowed quantized magnetic sublevels. In cesium, the doublet ground state energy separation is about 0.3 cm^{-1}, or 9.1926 Gc/sec., according to Arditi and Carver.[1] The magnetic moment of cesium, $I = 7/2$, combines with the $J = 1/2$ of the ground state doublet in $(I + J)$ and $(I - J)$ combinations to provide seven magnetic sublevels, viz., M_F = 3, 2, 1, 0, -1, -2, and -3 in the lower lying and nine magnetic sublevels, viz., M_F = 4, 3, 2, 1, 0, -1, -2, -3, and -4 in the upper lying of this doublet. Energy separations of these magnetic sublevels amounts to only 350 kc/sec/gauss.

Absorption of cesium resonance radiation of 8943.5 Å causes atomic transitions in cesium vapor from the ground state to the first excited state $^2P_{1/2}$. If the light is not polarized, the relative population of the cesium ground state levels is unaffected. If circularly polarized light is incident, absorptive transitions occur according to the selection rule $\Delta M_F = \pm 1$, and re-radiation (by spontaneous emission) occurs according to $\Delta M_F = \pm 1, 0$. If we allow only $\Delta M_F = +1$ transitions in absorption, the result over a long period of time for cesium will be an overpopulation of atoms in the $M_F = +4$ sublevel of the upper lying of the ground state doublet; similarly, an overpopulation of the $M_F = -4$ sublevel exists for $\Delta M_F = -1$ absorptions. The existence of a magnetic field along the direction of propagation is implied, but the magnitude required is only at the one gauss level.

APPLICATION TO MIROS

For MIROS, we wish one light beam to selectively populate atomic levels and a second beam to reduce these populations. From the above theoretical arguments one may see that at any one moment in a particular dynamic system, (say, $\Delta M_F = +1$), we are "driving" the atoms to the $M_F = +4$ level and that we can interrupt the process with radiation by causing transitions (1) between magnetic sublevels of the same doublet state, (2) between magnetic sublevels of the two doublet states, and (3) between one level of the ground state and a higher lying excited state.

Attempts have been made in this work to show that cross-modulation may be effected by all of these means. The method described in (3) above was originally carried out with an unpolarized beam from a second cesium source.

---

1. Arditi and Carver, Phys. Rev., 112, 449, 1958.

The method described in (2) was carried out with a klystron source at the required resonance frequency and a horn antenna, and the method described in (1) was carried out with a signal generator which provided current to a coil wrapped around the cesium vapor bulb used for the optical pumping work.

MIROS aims may be fulfilled by using source combinations of optical frequencies or one optical and one microwave frequency source, or even one optical and one low frequency source. The deciding factor is the ability to transmit the energy to the MIROS element. One optical frequency is necessary to obtain the optical pumping, but the de-pumping frequency is not restricted to the optical range.

The light sources for MIROS are expected to be of the laser type, probably injection lasers because of their tunability. Measurement of optical pumping sensitivities, previously reported, indicates that microwatt power levels are sufficient for detectable effects. However, two major factors are important in systems considerations: the first is reduction in power due to beam divergence, and the second is incident solar radiation at the wavelength of interest. At 8950 Å, solar radiation at a satellite within the Doppler-broadened cesium line (room temperature) is about 0.1 microwatt per cm^2, which is three times the level predicted for a 10-watt laser of 10 sec divergence angle. Obviously, direct incidence of solar radiation on any MIROS optical pumping element would cause loss of intelligence with this size pumping source unless other precautions are taken to shield the element against such unwanted radiation or to make use of stronger transmitted signal levels.

EXPERIMENTAL WORK

A. Microwave

The zero magnetic field splitting of the cesium doublet ground state, as measured by Arditi and Carver,[2] corresponds to a frequency of 9192.6 Mc/sec. The width of the absorption line is narrow, and the exact frequency depends on nature and pressure of the buffer gas in the absorption cell. The predicted resonance was found by this staff making use of a klystron source tuned to the 9.19 Gc/sec frequency range and sweeping frequency through the resonance value. Energy was transmitted to the absorption cell through waveguide terminated by a horn antenna located adjacent to the absorption cell. The power level is not known but should be in the milliwatt range based on specifications provided by the manufacturer. Stability of the klystron at the exact resonance frequency makes amplitude modulation difficult. However, in spite of the frequency drift of the klystron, it has been possible to observe indications of optical pumping modulations with amplitude modulation at 1000 cps of the klystron. A decrease in optical pumping has been observed for two

---

2. Ibid

orientations of the horn antenna, corresponding to the RF magnetic field direction being both parallel and perpendicular to the direction of propagation. Amount of decrease of the optical pumping signal, as observed with an oscilloscope, varied up to about 50%, depending on klystron operation. Frequency sweep of the klystron produced variation in the optical pumping signal and suggests the attractive possibility of producing cross modulation by frequency modulation of a microwave oscillator.

B. Radio Frequency

A decrease of optical pumping signal was obtained by sending current from a signal generator through a loosely wound coil wrapped around the bulb so that a magnetic field could be applied normal to the direction of propagation. In the presence of a changing axial magnetic field, the resonance line is quite wide, as one might expect. With a steady DC axial magnetic field, the resonance frequency at 350 Kc/sec/gauss should vary linearly with the magnetic field. The current in the Helmholtz coils used to produce the axial DC field was varied from 10 to 100 ma, and a plot of seven points does show a linear variation of resonance frequency with current from 200 to 1000 Kc/sec. The resonance line appears to be very sharp,[3] but actual frequency spread was not measured. Change in optical pumping signal corresponds well with that observed with klystron energy irradiation.

C. Solar Cell

It is apparent that the degree of optical pumping obtained is dependent on the existence of an axial magnetic field. In order to show that auxiliary, but passive, equipment may be used, a conventional Hoffman silicon solar cell was irradiated with unfiltered light from a 6 V tungsten bulb, and the output current was allowed to flow through the DC axial field Helmholtz coils. Chopping the light at 1 Kc/sec produced a sizeable optical pumping signal at this frequency. Application of the scheme to MIROS would involve one light source exciting a solar cell complex which in turn produces the magnetic field to allow optical pumping by a second light source. The effect is easily demonstrable, but considerable care is required in assembling an operable system for field use.

---

3. For similar transitions ($\Delta F = 0$, $\Delta M_F = 1$) a line width of 7.5 Kc/sec has been reported for Cs by T. Skalinski, J. Phys. Radium, 19, 890, (1958).

D. Optical Considerations

In order to test the feasibility of using a corner cube as a MIROS reflector with a cesium optical pumping experiment, the experimental program this period also included the observation of signal strength when the circularly polarized pumping light is reflected back through the cell by a small quartz corner cube. In order to observe the reflected light with a photomultiplier, a half-silvered mirror was inserted in the pumping light path. Good optical pumping was observed with the corner cube, but relative intensity measurements were not attempted.

Other cesium sources were made in this laboratory using xenon as a filling gas at 1 mm pressure. Both small bulb and capillary configurations were tried, but the latter seem to produce the better intensity. No detailed tests have been made with these new bulbs, but it is hoped that good modulated electrodeless discharges may be obtained.

An interesting effect has been observed with the AC-operated Osram source. Stability of operation has been obtained in previous work by operation in an oil bath with optical pumping levels at 1 to 10 percent of the total light monitored by the photomultiplier. A critical temperature of operation of the lamp has been discovered at which as much as 20 percent optical pumping may be obtained. This point is being further pursued.

PRINCIPAL INVESTIGATORS' TIME DEVOTED TO WORK

The principal investigators performing the work and the time devoted to this work by these individuals from 21 August to 21 September 1963 are as follows:

Personnel	Man-Hours
B. Harned	71
L. Leder	64

PLANS FOR THE NEXT INTERVAL

Having shown the feasibility of using several techniques in optical pumping to produce a modulation transfer, we are anxious to incorporate one or more of these techniques in a demonstration model which will yield useful information on frequency response and possible distortion characteristics. Although not readily applicable for transmission purposes in MIROS, our first choice for this work will be the relatively low frequency Zeeman resonance line at about 350 Kc/sec. Further investigation of the light sources will be conducted. The preparation of light sources has proved to be inexpensive and allows for the preparation of alternate absorption cells.

BWHarned

B. W. Harned
Senior Research Specialist

M E Lasser

M. E. Lasser
Manager, Applied Physics Research